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BRIGHTNESS CONTRAST: A REINTERPRETATION OF COMPOUND CUE AND COMBINED CUE EXPERIMENTS WITH PIGEONS

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A group of three pigeons was trained on a 4-ply multiple schedule: a green color and a vertical line superimposed upon an achromatic background as positive stimuli, and a red color and a horizontal line on an achromatic background as negative stimuli. The pigeons were tested with the vertical line superimposed upon different achromatic background intensities, then with the vertical line superimposed upon different green background intensities, and finally with the vertical line and its training achromatic background attenuated (and unattenuated) by a neutral density filter. The gradients peaked at the luminance of the achromatic background used during training and at the equivalent luminance for the green background when it was substituted for the achromatic background. The brightness contrast, not the background luminance, was the critical variable as the neutral density filter attenuated both the line and the background equally, leaving brightness contrast unchanged; there was no response decrement to this attenuated stimulus. Two other groups of three pigeons showed that they attended to line orientation as well as to brightness contrast. The brightness contrast hypothesis was extended to explain results of attention experiments and combined cue experiments which have used line stimuli in combinations with different backgrounds.

Key words: discrimination, stimulus control, combined cue, compound stimulus, overshadowing, blocking, variable-interval schedule, key peck, pigeons

Any complete description of behavior entails a description of the controlling stimuli. In some cases, the controlling stimuli may elude identification by the exeprimenter, and chances for such elusion increase when the stimulus is a compound of several elements. For example, in studies of compound stimulus control (Born & Peterson, 1969; Honig, 1970; Johnson & Cumming, 1968), pigeons have been trained to discriminate compound stimuli consisting of geometric forms over colored or non-colored backgrounds. Typically, in testing, the pigeons responded very little to superimposed forms presented alone and these low response rates did not distinguish among the forms. The experimenters have implicitly assumed that it was valid to present the components of the compound stimulus separately in order to assess control by each one. The strength of their conclusions depends upon the validity of the assumption that the form and background elements are independent. Historically, this assumption of cue independence was basic to the continuity tradition where the excitatory strength to a compound stimulus was assumed to equal the algebraic addition of the excitatory strengths of the component cues (Spence, 1936). Several contemporary theories (e.g., Blough, 1975; Rescorla & Wagner, 1972) have adopted this assumption of cue independence and the consequent prediction of additivity of response strengths. While this assumption may hold in some situations, the experiments in this article show that it does not hold when pigeons view lines on backgrounds as formerly assumed (Johnson & Cumming, 1968). The experiments of this article show that line stimuli cannot be separated from their backgrounds. A white line always has a background, whether it be colored or dark, and pigeons are shown to attend to the line-background relationship.

We think it is important to note that these experiments and their outcomes were not deduced from the existing body of literature, but rather evolved through analysis and discussion

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of the seemingly inexplicable results as the experiments were conducted, one-by-one. (The actual order of conducting the experiments was just the reverse of that reported in this article.)

EXPERIMENT 1

The objective of this experiment was to determine whether or not pigeons trained in a successive discrimination involving separate presentations of green and red colors and vertical and horizontal line orientations would attend to the brightness contrast between the line and background, or to the components themselves. In the first phase, extinction testing was conducted with the vertical line superimposed upon different intensities of a white background. In the second phase, extinction testing was conducted with the vertical line superimposed upon different intensities of a green background. In the third phase, extinction testing was conducted with a neutral density filter attenuating both line and background to change the intensity but not its contrast.

PHASE 1

METHOD

Subjects

The subjects were three adult (4- to 5-yr-old) experimentally naive White Carneaux pigeons from the Palmetto Pigeon Plant of Sumter, South Carolina. They were maintained between 77% and 83% of their free-feeding weights during the experiment.

Apparatus

The pigeons were trained and tested in a one-key pigeon chamber (Scientific Prototype Corporation, Model B200). The chamber was enclosed within a chemical fume hood, which isolated the pigeons from outside disturbances. A 10 watt tungsten light bulb mounted inside the hood diffusely illuminated the chamber through its Plexiglas top and sides.

Visual stimuli transilluminated a screen located .84 cm (.33 in) behind the plastic transparent pecking key. The pecking key was 2.5 cm (1 in.) in diameter. The minimum force required to operate the key was 0.3 N. The stimuli were projected via a 12-stimuli one-plane readout projection unit (Industrial Electronic Engineers Model 0010-01-1820) provided with Sylvania 1820 Miniature light bulbs. The projection film provided 12 individual solid white lines of different angular orientations over a black background. The projected image of each line was 2.3 cm long and 0.2 cm wide. The system was subsequently modified to provide a red background (Kodak Wratten gelatin filter No. 29), a green background (Kodak Wratten gelatin filter No. 55), and white backgrounds of different luminances (Kodak Wratten gelatin neutral density filters No. 96).

Stimuli were calibrated with an Edgerton, Germehausen and Grier (EG&G, Inc.) Model 580-585 high sensitivity spectroradiometer system with a Model 585-60 Series detector head. Radiometric determinations for each stimulus were obtained from 520 to 700 nm at 20 nm steps. The obtained values were corrected at each wavelength for the sensitivity of the spectroradiometer by measures supplied by the manufacturer. The radiometric measurements were then multiplied by the pigeon's photopic spectral sensitivity coefficients (Blough, 1957). These resulting photometric values were used to determine total luminance between 520 nm and 700 nm by an integration procedure employing a trapezoidal rule to calculate the area between adjacent calibrations. The white-line relative luminance equaled the unattenuated white background. This corresponded to a luminance of 15.8 millilamberts (50.3 cd/m^2) as measured with an SEI exposure meter.

A system of relays, timers, and counters controlled session events and recorded data.

Procedure

Prediscrimination training. On the first day, the subjects were adapted to the experimental chamber for 30 min. With the hopper light on, they received their daily ration of mixed grain. In the following two days, the subjects' responses were shaped to the pecking key. During the key-peck shaping, randomized presentations of 2.2G and 11.8W + L90° were projected over the key. Here 2.2G represents a green background with 2.2 relative units luminance and 11.8W + L90° represents a vertical line superimposed over an 11.8 relative units white background. Each presentation was of 30 sec duration and each response to these stimuli was reinforced by a 3-sec access to food. At the end of the shaping procedure, each bird had received 25 continuous rein-

Table 1

Stimuli and Procedures for Phase 1 of Experiment 1

Stimulus backgrounds were either green (G), red (R), or white (W), and the prefix is the relative background luminance. Superimposed lines are in degrees of orientation where 90° is vertical.

Procedure	*Sessions*	*Stimulus presentations per session*	*Stimulus background luminance and line orientation*				
			S+		*S−*		
Training:							
1	5	50	2.2G	11.8W+L90°	2.2R	11.8W+L0°	
2	5	50		11.8W+L90°		11.8W+L0°	
Testing	1	2 of 2.2R			2.2R	11.8W	11.8W+L90°
		2 of 11.8W			2.2G	L90°	13W+L90°
		5 of others			2.2G+L90°	4W+L90°	23W+L90°

forcements for pecks to the above stimuli at the key.

Discrimination training and testing. On the second day, subjects received 25 successive presentations each of 2.2G, 2.2R, 11.8W + L0°, and 11.8W + L90°, where 2.2R was a red background of 2.2 relative units luminance and 11.8W + L0° was a horizontal line over a 11.8 relative units white background. Responses were occasionally reinforced with 3-sec access to mixed grain in the positive stimuli (S+), 2.2G or 11.8W + L90°, on a variable-interval (VI) 15-sec reinforcement schedule. No reinforcement was given for responses in the negative stimuli (S−), 2.2R or 11.8W + L0°. Immediately afterwards, the birds received the same number of stimuli with a VI 30-sec reinforcement schedule in effect during positive stimulus presentations. On following training sessions, a VI 1-min reinforcement schedule was in effect in S+ presentations. Stimuli presentations were randomized within blocks of the four training stimuli. The stimuli and procedures for Phase 1 discrimination training and testing are summarized in Table 1.

At the end of the first five training sessions, all pigeons had acquired a discrimination index (responses to S+ divided by the addition of responses to S+ and S−) of better than 90% in the color (green-red) discrimination, but less than 90% in the line orientation (vertical-horizontal) discrimination. Overtraining may sharpen relative gradients of orientation (Hearst and Koresko, 1968) and flatten wavelength generalization gradients (Friedman & Guttman, 1965). Therefore, the birds received five additional sessions involving the line orientation discrimination only. At the end of these five training sessions, all birds had acquired the 90% discrimination index on the line orientation problem, too. The next day the pigeons received a short warm-up training session of 12 presentations (three of each stimulus). Then extinction testing began. Each test stimulus was displayed for 30 sec with a 10-sec dark intertrial interval. The presentations were randomized within blocks, with each block containing one presentation of each stimulus.

Results

The upper panel of Figure 1 shows the mean of the response rates, normalized with respect to the response rate to the vertical line training stimulus 11.8W + L90°. (Individual response rate data are shown in Table A of the Appendix.) The generalization gradient of this upper panel is peaked at 11.8W + L90° along the luminance continuum. Unlike the substantial responding to the S+, there was almost no responding to 2.2R, 11.8W, and L90° (these data are not shown in the Figure). Responding to the compound 2.2G + L90° was intermediate to the components (2.2G and L90°) tested separately, and this datum point is located on the generalization curve for achromatic luminance. Because generalization to the line on the green background fell on the generalization function for achromatic luminance, background luminance or some interaction between background luminance and line luminance may be more important than color.

Phase 2

The purpose of Phase 2 was to further assess the role of background luminance. This study used generalization testing at several

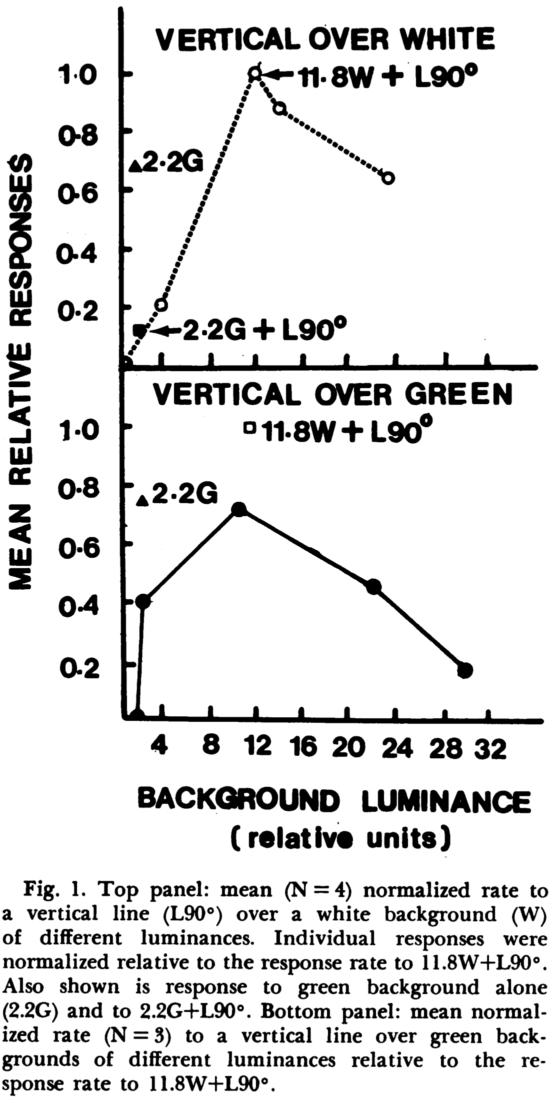

Fig. 1. Top panel: mean (N = 4) normalized rate to a vertical line (L90°) over a white background (W) of different luminances. Individual responses were normalized relative to the response rate to 11.8W+L90°. Also shown is response to green background alone (2.2G) and to 2.2G+L90°. Bottom panel: mean normalized rate (N = 3) to a vertical line over green backgrounds of different luminances relative to the response rate to 11.8W+L90°.

values of green background luminance with the superimposed vertical line.

Method

Subjects and Apparatus

The subjects and apparatus used in Phase 1 were used in Phase 2.

Procedure

The pigeons were retrained in a single session with the same procedure used in Phase 1. Each stimulus was presented 25 times with a VI 1-min reinforcement schedule in effect during S+ presentations. The next day, the pigeons received a short warm-up session with two presentations of each stimulus with a VI 1-min schedule of reinforcement in the positive stimuli. Immediately afterwards, testing was conducted in extinction as in Phase 1 but with different intensities of green background rather than white background. The stimuli and procedures for Phase 2 training and testing are summarized in Table 2.

Results

The lower panel of Figure 1 shows the mean of the response rates, normalized relative to the response rate to 11.8W + L90°. (Individual response rate data are shown in Table B of the Appendix.) The generalization gradient peaked near the 11.8 relative luminance level, but the peak was below the rate to the positive training compound, 11.8W + L90°. A possible reason why no green background luminance explored produced as much responding as did the achromatic training background was that there were five times as many extinction presentations containing the green background as there were containing the achromatic background. Table 3 shows that responding to stimuli containing a green background indeed extinguished more rapidly than

Table 2

Stimuli and Procedures for Phase 2 of Experiment 1

Stimulus backgrounds were either green (G), red (R), or white (W), and the prefix is the relative background luminance. Superimposed lines are in degrees of orientation where 90° is vertical.

Procedure	Sessions	*Stimulus presentations per session*	*Stimulus background luminance and line orientation* S+		S−		
Retraining	1	25	2.2G	11.8W+L90°		2.2R	11.8W+L0°
Testing	1	2 of 2.2R			2.2R	11.8W+L90°	10G+L90°
		2 of 11.8W			11.8W	1G+L90°	22G+L90°
		4 of others			2.2G	2.2G+L90°	30G+L90°

Table 3

Mean (N = 3) Relative Responses per Block during Phase 2 of Experiment 1

	Test Stimulus								
Block	*2.2R*	*11.8W*	*2.2G*	*1G+L90°*	*2.2G+ L90°*	*10G+ L90°*	*22G+ L90°*	*30G+ L90°*	*11.8W+ L90°*
1	–	0	.84	0	.48	.84	.48	.34	1
2	0	–	.79	0	.45	.75	.50	.23	1
3	–	0	.71	0	.33	.67	.38	.10	1
4	0	–	.64	0	.30	.56	.43	.13	1

responding to the stimulus with the achromatic training background. The peak of the gradient occurred at a background luminance approximately equal to that of the white training stimulus, but different from the relative luminance (2.2) of the green training stimulus. Therefore, in the compound background, luminance, not color, is important. The controlling stimulus could be luminance contrast, however, and Phase 3 explored this relationship.

Phase 3

The purpose of Phase 3 was to determine whether the background luminance or the line-background luminance relationship (brightness contrast) was the critical stimulus dimension. This determination was made by superimposing a neutral density filter and consequently changing total stimulus luminance while keeping the line to background luminance ratio constant. A lack of response decrement under these conditions would indicate that brightness contrast alone was the controlling dimension. (Note: We have chosen to use the term *brightness contrast* as opposed to alternatives such as luminance contrast, because brightness contrast labels the dimension from the subject's point of view. Experimenters control luminance, but subjects discriminate brightness. It would be incorrect—indeed, a Titchenerian stimulus error—to speak of subjects making luminance contrast discriminations.)

Method

Subjects and Apparatus

The same subjects and apparatus used in Phase 1 and Phase 2 were used in Phase 3. A Kodak .3 log neutral density filter could be superimposed between the stimulus display and the clear pecking key through which the pigeon viewed the stimulus. This neutral density filter approximately halved the luminance of the display.

Procedure

The training procedure used in Phase 2 was followed in Phase 3. Stimuli, training, and testing conditions are indicated in Table 4. The test stimuli were each presented with and without a neutral density filter in place. Testing in extinction included four blocks of the six stimuli presented in a different order in each block.

Results

Figure 2 shows the normalized mean responses per block for the four compound test stimuli. (Individual response rate data are

Table 4

Stimuli and Procedures for Phase 3 of Experiment 1

Stimulus backgrounds were either green (G), red (R), or white (W), and the prefix is the relative background luminance. Superimposed lines are in degrees of orientation where 90° is vertical.

			Stimulus background luminance and line orientation			
Procedure	*Sessions*	*Stimulus presentations per session*	*S+*		*S–*	
Retraining	1	25	2.2G	11.8W+L90°	2.2R	11.8W+L0°
Testing	1	4			2.2G 2.2G+L90° 11.8W+L90°	(plus each stimulus attenuated 0.3 log unit)

shown in Table C of the Appendix.) A three-way analysis of variance of Object × Filter × Block was carried out considering Stimuli Objects (green alone, vertical over green background, and vertical over white background), Filter condition (filter and no filter), and Blocks (1 to 4). Three scores (three pigeons' responses) were included in each cell matrix. The important result was that the filter condition was not significantly different from the no filter condition. Only the Object effect was significant, $F(2,48) = 5.53$, $p < .01$. A Newman-Keuls multiple range test for Object effect revealed no significant difference between the green and the vertical over white background means, although both were significantly different from the vertical over green mean.

Discussion

The finding that the filter condition had no significant effect strongly indicated that brightness contrast was the main controlling variable. Since addition of the filter approximately halved the background luminance, a 60% relative responding level decrease would have been expected on the basis of the generalization decrement results from Phase 1. (See Figure 1. At 6 relative luminance units, or approximately half the luminance of the 11.8 relative luminance white training background, there was a 60% drop in responding relative to the 11.8W + L90° training stimulus.) Likewise, nearly a 40% decrease in the responding level to the vertical line over the green background would have been expected in terms of background luminances on the basis of the generalization decrement results from Phase 2.

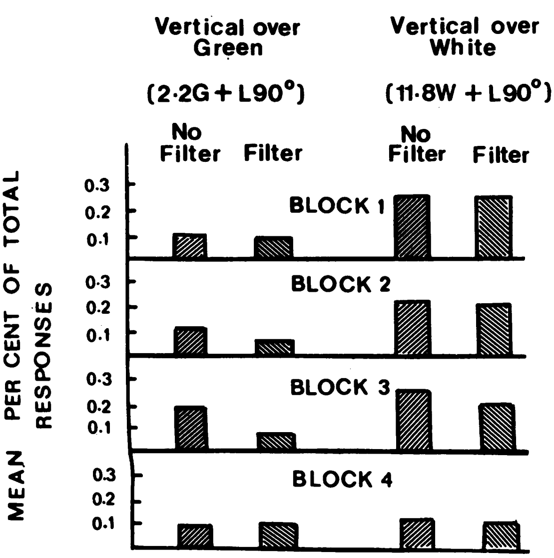

Fig. 2. Mean (N = 3) of total responses in Phase 3 of Experiment 1, expressed as a percent of total responses per block of extinction testing. Numbers (2.2, 11.8) preceding G and W refer to relative luminances of these backgrounds.

Our filter experiment left the luminance ratio between the line and its background unchanged which in turn left the Weber-Fechner ratio constant. The crucial question for evaluating what if any changes occurred in the pigeons' perception of brightness contrast is: How does this variable, luminance ratio, relate to brightness contrast for pigeons? Weber's law ($\Delta I/I = \text{constant}$) says that they are isomorphic; a constant luminance ratio will produce constant brightness contrast sensitivity. Translated, this means that for just detectable brightness contrast (equal brightness contrast) the luminance ratio should be constant for all values of the background luminance. For humans, (König & Brodhum, 1889, after Hecht, 1934) the Weber-Fechner ratio is fairly constant for medium and high luminance values. Pigeons likewise seem to have a luminance region where the Weber-Fechner ratio is fairly constant (Shumake, Hatfield, & Smith, 1966), and the luminance change produced by the filter was probably within this constant region, as the pigeons exhibited no change in response strength to the attenuated stimulus.

Are there other dimensions of the line-background stimulus other than brightness contrast that control behavior? Experiments 2 and 3 addressed this question.

EXPERIMENT 2

This experiment was designed to determine whether or not subjects were under the control of the line orientation dimension. It was also a test of the brightness contrast hypothesis. The green training stimulus was luminance matched to the achromatic training background. Generalization gradients for different line orientations on the green background consequently should, according to the brightness contrast hypothesis, be equal to those generalization gradients for different line orientations on the achromatic training background.

Method

Subjects

The subjects were three adult (3- to 5-yr-old) experimentally naive White Carneaux pigeons, maintained between 77% and 83% of their free-feeding weights during the experiment.

Apparatus

As in Experiment 1.

Procedure

Prediscrimination training. Subjects were adapted to the chamber during the first day. During the following three days, the subjects' responses were shaped in the presence of 2.2G and 2.2W + L90°. The stimulus presentations were randomized, each one of 30-sec duration. After shaping their responses, each pigeon received 25 consecutive reinforcements for pecks on the key to the above stimuli. They then received 25 presentations each of: 2.2G, 2.2W + L90°, 2.2R, and 2.2W + L0°. Responses to 2.2G and 2.2W + L90° (positive stimuli) were under a reinforcement schedule of VI 15-sec, while responses to 2.2R and 2.2W + L0° were not reinforced. Immediately afterwards, they received 25 presentations of each of these four stimuli with responses to the positive stimuli under a VI 30-sec schedule of reinforcement. Reinforcement consisted of 3-sec access to food. Each stimulus duration was 30 sec with a 10-sec intertrial interval.

Discrimination training and testing. Stimuli and procedures for Experiment 2 are indicated in Table 5. Subjects were reinforced under a VI 1-min schedule of reinforcement in both positive stimuli, and after 10 sessions they had achieved a 90% or more discrimination index on both the line orientation and color problems. Subjects were then tested in extinction in a single session. The session consisted of four blocks of randomized presentations of the testing stimuli. Each block included one presentation each of the 12 line orientations on the green background, one presentation each of the 12 line orientations on the white background, three presentations each of the red and green stimulus, and one presentation each of the line on dark background and the white background alone in every other block.

Results

Figure 3 shows the response rates of the individual subjects to the testing stimuli. The generalization gradients were similar for the white and green backgrounds. As in Experiment 1, there was almost no responding to the vertical line over the dark background and almost no responding to the white background alone. These results are not shown in Figure 3.

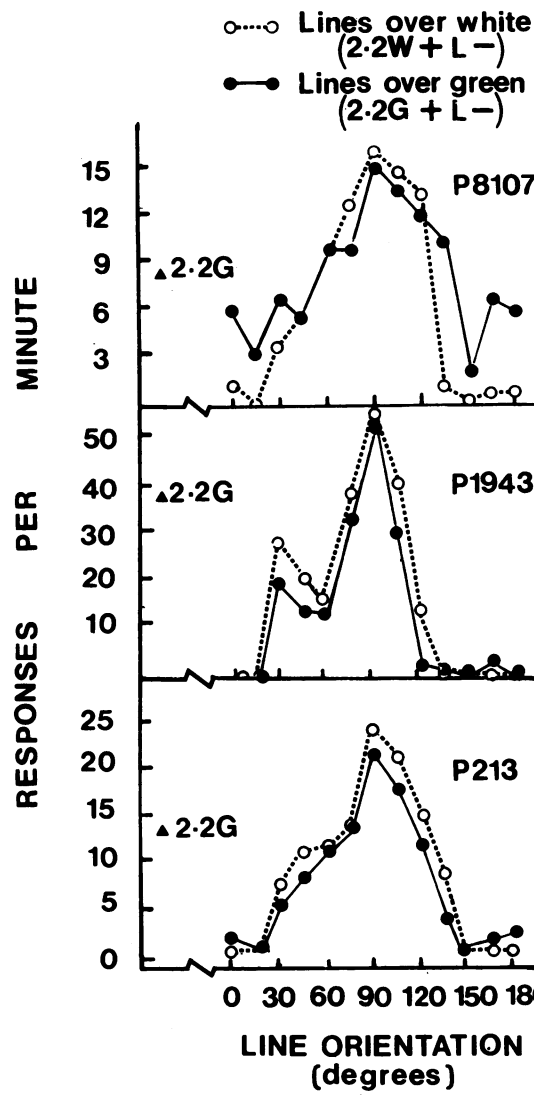

Fig. 3. Individual response rates to 12 different line orientations over a green background (filled circles), and over a white background (unfilled circles) of matching luminances (2.2 relative units). Also shown is the response rate to the green background (2.2G). The symbol 90° stands for the vertical line, 0° and 180° stand for the horizontal line.

Table 5

Stimuli and Procedures for Experiment 2

Stimulus backgrounds were either green (G), red (R), or white (W), and the prefix is the relative background luminance. Superimposed lines are in degrees of orientation where 90° is vertical.

Procedure	Sessions	Stimulus presentations per session	Stimulus background luminance and line orientation							
				S+			*S−*			
Training 1	5	50	2.2G	2.2W+L90°			2.2W+L0°	2.2R		
Training 2	5	50		2.2W+L90°			2.2W+L0°			
Testing	1	12 of 2.2G			2.2R	2.2G+L45°	2.2G+L120°	L90°	2.2W+L45°	2.2W+L120°
		12 of 2.2R			2.2G	2.2G+L60°	2.2G+L135°	2.2W	2.2W+L60°	2.2W+L135°
		2 of 2.2W			2.2G+L0°	2.2G+L75°	2.2G+L150°	2.2W+L0°	2.2W+L75°	2.2W+L150°
		2 of L90°			2.2G+L15°	2.2G+L90°	2.2G+L165°	2.2W+L15°	2.2W+L90°	2.2W+L165°
		4 of others			2.2G+L30°	2.2G+L105°		2.2W+L30°	2.2W+L105°	

Table 6

Stimuli and Procedures for Experiment 3

Stimulus backgrounds were either green (G), red (R), or white (W), and the prefix is the relative background luminance. Superimposed lines are in degrees of orientation where 90° is vertical.

Procedure	Sessions	Stimulus presentations per session	Stimulus background luminance and line orientation							
				S+			*S−*			
Training 1	5	50	2.2G	18W+L90°			18W+L0°	2.2R		
Training 2	5	50		18W+L90°			18W+L0°			
Testing	1	12 of 2.2G			L90°	2.2G+L45°	2.2G+L120°	2.2R	18W+L45°	18W+L120°
		12 of 2.2R			2.2G	2.2G+L60°	2.2G+L135°	18W	18W+L60°	18W+L135°
		2 of 18W			2.2G+L0°	2.2G+L75°	2.2G+L150°	18W+L0°	18W+L75°	18W+L150°
		2 of L90°			2.2G+L15°	2.2G+L90°	2.2G+L165°	18W+L15°	18W+L90°	18W+L165°
		4 of others			2.2G+L30°	2.2G+L105°		18W+L30°	18W+L105°	

Responses to the vertical line over the green background were more numerous than responses to the green background alone for all three subjects.

Discussion

In Experiment 2, the green background and the white background were of equal luminance for the sensitivity of the pigeon's eye, and so they had equal brightness contrast when the lines were superimposed on these backgrounds. The generalization gradients were similar for these two stimuli which supports the hypothesis that brightness contrast between the line and its background is a major controlling variable.

The subjects also were under the control of the line orientation dimension. There were no apparent differences between the slopes of the generalization gradients for lines over the green background and for lines over the white background. Line orientation exerted similar control for both backgrounds.

An algebraic additive model of response strength does not account very well for the results of Experiment 2. There was much more responding to the compound stimulus (2.2G + L90°) than to the elements: vertical line on dark background and green alone. This, then, would be an example of under summation. The brightness contrast hypothesis accounts for such a result by the greatly altered contrast of the line on the dark background, relative to the contrast used in training of the line on the white background; this altered contrast resulted in a substantial generalization decrement to the line on a dark background.

EXPERIMENT 3

This experiment had design and purpose similar to Experiment 2. In this case, however, the difference between the training white background luminance (relative luminance = 18) and the green background luminance (relative luminance = 2.2) was very large. The brightness contrast hypothesis predicts less generalization to lines on the dimmer green background; the dimmer green background produces more brightness contrast between it and the white line than the brighter achromatic training background.

Method

Subjects

The subjects were three adult (4- to 5-yr-old) experimentally naive White Carneaux pigeons. They were maintained between 77% and 83% of their free-feeding weights during the experiment.

Apparatus

As in Experiments 1 and 2.

Procedure

Prediscrimination training. Adaptation to the training chamber was initiated in the first day. During the next few days, the subjects' key peck responses were shaped in the presence of 2.2G and 18W + L90°. Then they received 25 continuous reinforcements for pecking to those stimuli.

After shaping, they received 25 presentations each of 2.2G, 2.2R, 18W + L90°, and 18W + L0°. Responses to 2.2G and 18W + L90° (positive stimuli) were reinforced under VI 15-sec schedule of reinforcement, while responses to 2.2R and 18W + L0° (negative stimuli) were not reinforced. Immediately afterwards, they received 25 presentations each of the four above stimuli, with responses to the positive stimuli reinforced under a VI 30-sec reinforcement schedule.

Discrimination training and testing. Stimuli and training procedures are indicated in Table 6. At the end of the 10 training sessions, the subjects had acquired a discrimination index of 90% or more in both the color and line orientation discriminations. They were then tested as in Experiment 2.

Results

Figure 4 shows the response rates for individual subjects in the top three panels and the mean percent of total responding in the bottom panel. In all individual cases, the gradient of line orientations over the green background (relative background luminance = 2.2) is below that of the gradient of line orientations over the white background (relative background luminance = 18). When plotted as mean percentage of total responses, the gradient of lines over green background appears to be steeper in the vicinity of the vertical line (90°) than that for the white background. As in Experiments 1 and 2, there was almost no responding

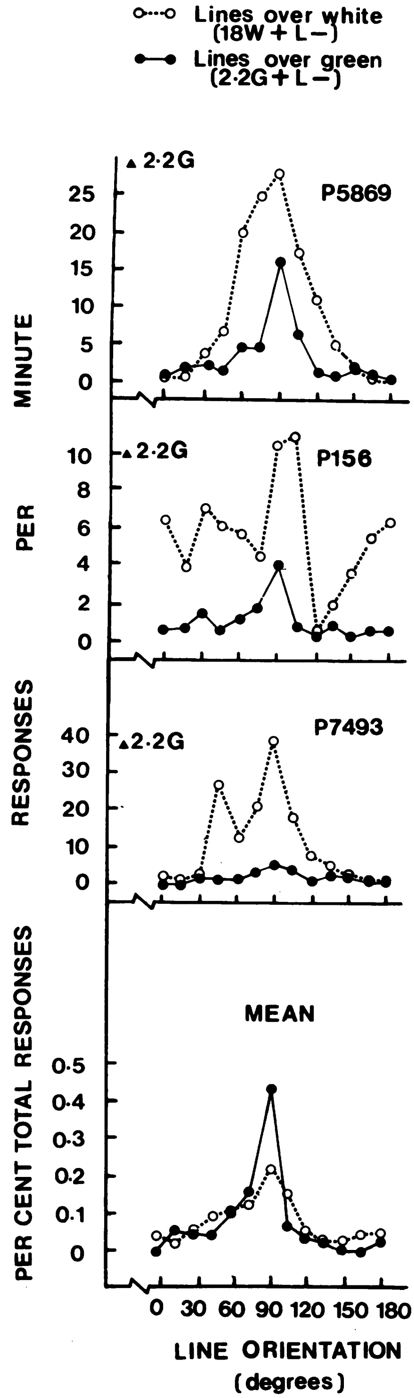

Fig. 4. Top three panels: individual response rates to 12 different orientations over the 2.2 units relative luminance green background (filled circles); and over the 18 units relative luminance white background (unfilled circles). Also shown is the response to the green background alone (2.2G). Lower panel: mean gradients expressed as percent of total responses for the three pigeons.

to the white line on the dark background or to the white training background alone. These results are not shown in Figure 6. Responding to 2.2G + L90° was intermediate to the response rate to the components: L90° and 2.2G.

Discussion

Like Experiment 2, an algebraic additive model of response strength cannot account for the results of Experiment 3; but, unlike Experiment 2, the results of Experiment 3 show over summation instead of under summation. Responding to the green alone stimulus plus responding to the vertical line on the dark background was much greater than responding to the compound of the two. Response strength models (additive or otherwise) cannot account for both the results of Experiments 2 and 3. The brightness contrast hypothesis accounted for the results of Experiment 2 and also accounts for the results of Experiment 3. Responding to the vertical-green compound was reduced by generalization decrement because the line-background brightness contrast of the compound was much greater than the line-background brightness contrast of the training stimulus. The much greater responding to the green alone stimulus than to the vertical-green compound in Experiment 3 is interesting because it shows that the pigeons did not attend to this background as a separate element. It is apparent that the role of the green stimulus when presented alone is quite independent of its role as a background stimulus for lines; in this latter role brightness contrast seems to dominate.

GENERAL DISCUSSION

Pigeons attend to the brightness contrast between a line and its background as shown by generalization tests with different achromatic background luminances (Experiment 1, Phase 1) and green background luminances (Experiment 1, Phase 2), or with different line orientations. The major result was that when the test background luminance equaled the training background luminance maximum responding was obtained, and it was as great for a green test background as it was for the original achromatic training background. The neutral density filter experiment (Experiment 1, Phase 3) showed that the brightness contrast between the line and the background was the important variable, not the background luminance itself.

The importance of brightness contrast as the controlling dimension leads us to the important conclusion that there is no such stimulus as a line "alone" stimulus (without a background); that a dark background simply provides maximum brightness contrast between the line and its background. It may be impossible to separate a line-background compound into its elements. Certainly, a white line on a dark background is not an element of a white line on a green background compound as shown by the results from the Experiments presented in this article. The concept of line "alone" may be the stumbling block in this kind of research involving colors, lines, and pigeons. It is provocative to think of response strengths to lines and colors adding together to provide the strong response strength to the compound of the two (Spence, 1936), but such simple addition of response strengths was not found in this study. The sum of the response rates to the elements (line on dark background, and green alone) was less than that to the compound (under summation) when the luminance of green and white backgrounds was matched (Experiment 2). On the other hand, the sum of the element response rates in Experiment 3 was much greater than that to the compound (over summation). The brightness contrast hypothesis can account for both the under summation and the over summation. In the case of under summation, there was strong responding to the compound because its line-background brightness contrast was equivalent to that of the training stimulus. Thus, it seems that one can obtain over summation, under summation, or anything between (even perfect summation) by choosing the right brightness contrast relationship between the training and test stimuli. This conclusion has important implications for the results of other experiments which have employed lines (or shapes) on backgrounds as stimuli for pigeons.

Many combined-cue tests have tested for a subtraction of response strengths rather than an addition of them. Typically, pigeons are trained to respond to a color (S+) and not to respond to a dark line (S−) on a white background (Davis, 1971; Rilling, Caplan, Howard, & Brown, 1975) or a white line on a dark background (Lyons, 1969; Yarczower, 1970; Yarczower & Evans, 1974). The test involves superimposing the line on the color to see if the S− stimulus (the line) has taken on the properties of a conditioned inhibitory stimulus. If the pigeon responds less to the color and line combined than to the color alone, then this is evidence, so they say, for the line being an inhibitory stimulus and subtracting some of the excitatory strength which has accrued during conditioning to the positive stimulus (color). Indeed, Hearst (1972) has said that such a test is the most definitive test for inhibitory stimulus control. Alternatively, these results, which seem to provide good evidence for conditioned inhibitory control, may simply be the result of a fortuitous change in the line-background brightness contrast. In those experiments where the line "alone" stimulus was a white line on a dark background (Lyons, 1969; Yarczower, 1970; Yarczower & Evans, 1974), the line-background brightness contrast was greatly reduced by superimposing the line on the colored background.Thus, the decrease in responding to this compound stimulus was probably due to generalization decrement from a change in brightness contrast when the line was superimposed on the colored background rather than due to the inhibitory line stimulus siphoning away some of the response strength of the colored background.

In other experiments where the line "alone" stimulus was a dark line on a white background (Davis, 1971; Drexler, 1974; Rilling et al., 1975) the brightness contrast of the combined stimulus might have been greater or it might have been less than that of the line "alone" stimulus. In either case, there might be a generalization decrement possibly attributed to a release from inhibition, due to the altered brightness contrast (see Figure 1). If the brightness contrast of the line-color combination was equal to the brightness contrast of the line "alone" stimulus (the S− stimulus used during training), then perhaps there would be no more responding to the combination than to the line "alone" during testing.

Line-background brightness contrast may be a major controlling variable in experiments where pigeons are trained on a line-background compound cue and later tested with the line "alone" (on a dark background) and the background alone. Typically, the purpose of these experiments is to determine to which stimulus the pigeon is attending, and whether or not one stimulus overshadows the potential control by the other stimulus. For example, Johnson and Cumming (1968) reinforced pigeons for pecking a vertical white line superimposed on a green background and did not reinforce them for pecking a horizontal white line superimposed upon a red background. When these components were later separated in a test, the pigeons responded very little or not at all to the white line on dark backgrounds. The brightness contrast hypothesis of this article explains this lack of responding to the line "alone" as the result of the much greater contrast of the lines on the dark background than the contrast of the lines on the colored backgrounds used during training. This brightness contrast hypothesis can also explain the results of other similar experiments (Born & Peterson, 1969; Honig, 1970).

In closing, it seems appropriate to point out that pigeons can be trained to respond to the background color of a line-background stimulus, independent (probably) of any line-background brightness contrast simliarities or differences (Blough, 1972). Of course, if one is interested in problems of blocking, overshadowing, multiple-cue learning, or attention, then any such explicit training would contaminate these experiments. Therefore, for such problems, it seems best to present stimuli other than lines on backgrounds to the pigeons. The appropriate stimuli may be elusive. Does a lack of perfect summation mean that summation does not hold, or does it mean that there is a stimulus configural interaction such as the line-background brightness contrast found in this series of experiments? Even when the stimuli are from different sensory modalities (Guth, 1967; Millier & Beale, 1977; Weiss, 1971; Woodbury, 1943), summation may not be found and configural interactions may have been the cause of these failures to find summation.

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APPENDIX

Table A

Response Rate in Extinction to Test Stimuli for Phase 1 of Experiment 1
(Responses/Minute)

	Test stimulus								
Subject	*2.2R*	*2.2G*	*2.2G+ L90°*	*11.8W*	*L90°*	*4W+ L90°*	*11.8W+ L90°*	*13W+ L90°*	*23W+ L90°*
3481	0	25.6	7.1	0	0	15	42	38	25.2
3461	0	25.8	4	0	0	4	33	28	26.4
9531	0	30.4	2.7	1	0	5	38	36.1	32.3

Table B

Response Rate in Extinction to Test Stimuli for Phase 2 of Experiment 1
(Responses/Minute)

	Test stimulus								
Subject	*2.2R*	*11.8W*	*2.2G*	*1G+ L90°*	*2.2G+ L90°*	*10G+ L90°*	*22G+ L90°*	*30G+ L90°*	*11.8W+ L90°*
3481	0	1	32	0	11.8	24.5	19.6	9.8	49.2
3461	0	0	21.6	0	10.8	20	12	6.8	27
9531	0	0	41.6	0	29	44.2	26	7.8	52

Table C

Response Rate in Extinction to Test Stimuli for Phase 3 of Experiment 1
(Responses/Minute)

		Test stimulus					
Subject	*Block*	*1.1G*	*2.2G*	*1.1G+L90°*	*2.2G+L90°*	*6W+L90°*	*11.8W+L90°*
3481	1	23	20	7	15	34	32
	2	9	22	9	8	14	22
	3	8	34	3	5	19	19
	4	16	16	10	7	19	16
3461	1	10	26	1	3	11	19
	2	21	17	1	1	10	15
	3	17	28	2	3	15	18
	4	22	22	1	1	10	14
9531	1	15	17	0	0	17	13
	2	28	24	5	5	9	13
	3	7	14	5	3	4	9
	4	15	17	0	0	4	9